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PLASTICS TECHNICAL EVALUATION CENTER
PICATINNY ARSENAL, DOVER, N. J.

# STUDIES IN TEAR RESISTANCE OF VULCANIZED RUBBER

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| Project No.: | TB4-521E |
| Report No.: | 1 |
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| Date: | 12 June 1952 |

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# STUDIES IN TEAR RESISTANCE OF VULCANIZED RUBBER

## Object

The object of this investigation was to study the mechanism involved in the tearing of rubber and ultimately to develop a reproducible laboratory method for measuring tear resistance which would be indicative of the life of Ordnance rubber material in service.

## Summary

A survey of the literature with reference to tear resistance of rubber has indicated that presently used methods of measuring the resistance of rubber vulcanizates to tearing are inadequate in that none furnish data of sufficient reproducibility. The basic mechanism involved in the tearing of rubber is extremely complex, owing to the fact that it differs with the type polymer being

tested and also because of the numerous variables associated with this type of test. Some of the requirements of a good tear test and the many variables in testing are listed herein.

In pursuit of the above objective, a program (Appendix I) was drawn up and submitted to Office, Chief of Ordnance, and the SAE-ASTM Technical Committee, Subsection IV J, on tear testing for their approval and/or comments. The program as approved was divided into four phases, as follows:

Phase I, Basic information for control purposes.

Phase II, Determination of mechanism of tear.

Phase III, Collation of results and deductions therefrom.

Phase IV, Specifications.

The work described in the present report is primarily concerned with Phases I and II of the overall program.

Results reported herein include information and data on the following factors entering into tear resistance:

1. Effect of molded ASTM (B) and Graves specimens versus die cut specimens.
2. Effect of varying the speed of elongation during testing from 5 to 240 inches per minute.
3. Influence of sample thickness on tear resistance.
4. Attempt to correlate tear resistance with conventional physical measurements.

5. Results of a compounding study, which was made to determine the effect of reinforcing filler particle size and structure on tear resistance, and also to determine the percent average deviation of tear resistance results in a series of compounds using three different polymers (Butyl, GR-S, and Hevea).
6. Percent average deviations in Scott tensile test results using vulcanizates prepared from the same three formulations as in 5. above.
7. Relationship of tear resistance and modulus using N.B.S. strain tester.
8. Results using various types of tear specimens.
9. Energy at rupture of Graves and ASTM (B) specimens at different rates of elongation.
10. Investigation of tear propagation under constant load.

## Conclusions

None of the factors concerned with tear resistance which have been investigated show any degree of positive correlation with tear resistance except tensile. It is believed that presently used tear specimens merely represent more complicated tensile specimens, since some positive correlation may be found between the tensile strength using the standard dumb-bell specimens and tear results using ASTM(B) and Graves specimens. It would appear from data thus far acquired that the lack of reproducibility in tear testing is not a great deal different from the lack of reproducibility using the standard tensile test. This is primarily caused by the non-homogeneity of the rubber vulcanizate itself when tested by a stress strain type of measurement.

## Recommendation

It is recommended that Phase III and IV of the program not be completed, since no definite conclusions can be otained from Phases I and II leading to a suitable test method or specification.

It is recommended that future Ordnance research and development work center on a test method which more closely simulates service conditions such as the cut-crack-chip resistance of rubber in heavy sections.

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## Contents

## Introduction

1. The two most commonly used laboratory methods of determining tear resistance in this country, namely, the Graves Angle test (ASTM D624-48 Die C) and the Crescent test (ASTM D624-48 Die A or B), do not have sufficient reproducibility, nor can they be relied upon to differentiate tear initiation and tear propagation. In addition, it is believed that presently used methods for estimating tear resistance do not reflect the true manner in which most tearing in service occurs. In a large majority of the cases of tearing in service, the tear occurs by a cutting, chipping, cracking or gouging method, rather than by the modified tensile type tear test as used in the laboratory. The latter test would apply mainly in the case of comparatively thin flat rubber articles, such as inner tubes, gaskets, boots, bellows, etc., whereas, the former type tearing would occur in much more prevalent Ordnance items, such as tires, bogie wheels, track blocks, etc. A great many other tear tests have been proposed(1) but none seem to possess good reproducibility or to correlate with the actual tearing of rubber articles in service. There is a great need for a tear test which will have the following characteristics:

A. Reproducibility ± 5 percent average deviation.

B. Differentiate between tear initiation and tear propagation.

C. Ease of manipulation - mechanical simplicity.

D. Applicable to all types of polymers.

E. Suitable for use in all states of cure of rubber and using various compounding ingredients.

F. Simulate the manner in which most tearing takes place in service.

That a better tear test is required is also indicated by the fact that Morris and Gerwels[2] found in a study of 21 different laboratories that values of tear strength differed by 79% as compared with differences of 28% in hardness, 15% elongation at break, 48% in tensile and 75% in modulus.

2. The mechanism involved in the tearing of rubber is extremely complex and difficult of analysis. It is made more involved by the fact that the mechanism may differ, depending upon whether the polymer used is a crystallizable or non-crystallizable type. Thus, butyl rubber frequently exhibits the phenomenon referred to as "knotty tear". Buist[3] states that this same effect may be observed in other polymers and he even found a case of knotty tear with a natural rubber gum stock. There appears to be much controversy in the literature with

reference to the question of tear initiation and tear propagation. Thus Buist[4] claims that the angle tear method (ASTM D624-48 Die C) gives a measure of tear initiation, whereas, the Crescent (ASTM D624-48 Die A or B) tear is a tear propagation method. On the other hand, Nijveld[5] cannot support this view. The latter author believes that in both tests a tear is initiated, with a tear being a propagation of an incision in the one and excision in the other.

3. Additional factors which complicate the study of tear testing are the numerous variables which are involved. Probably the most important of these are the following:

A. Mechanical fibering of the rubber under stress.

B. Stress distribution in the specimen - Shape of sample.

C. Speed of stretching.

D. Size and thickness of specimen and depth of nick.

E. Number of nicks and depth of nick in nicked type specimens.

F. State of cure.

G. Direction of grain.

H. Modulus.

I. Effect of reinforcing fillers - particle sizes.

J. Temperature of testing.

K. Length and degree of milling time.

L. Hardness of rubber compound.

M. Plasticizer type and amount.

N. Effect of crystallizability of polymer.

O. Effect of edge smoothness of specimens - die cut versus molded.

P. Radius of curvature of specimens.

## Procedure

4. With the object of studying the mechanism of tearing in rubber articles, a program was drawn up and submitted to the SAE-ASTM Sub-committee IV J for their comments and recommendations (See Appendix I). Briefly, this program as approved was divided into four broad phases, consisting of the following:

Phase I, Basic information for control purposes

Phase II, Determination of mechanism of tear

Phase III, Collation of results and deductions therefrom

Phase IV, Specification.

Most of the work included herein was under Phases I and II. Since there are so many variables associated with tear testing, it was decided to attempt to establish a backlog of basic information relative to tear testing and thus be able to eliminate at least a few of the variables. Therefore, three polymers were chosen based on the greatest usage and consisting of one non-crystallizable type (GR-S), one crystallizable type (Butyl), and natural rubber as a control, since such a great volume of work in the literature is reported relative to natural rubber. For the non-crystallizable type, GR-S 50 was selected, while butyl represented the crystallizable polymer. According to Buist[6], butyl rubber is a very convenient polymer to use in the study of the mechanism of tearing, since it has a high permanent set which is sensitive enough to show up some of the stress gradients in the sample.

5. A mold was prepared for curing the ASTM(B) and Graves tear specimens, and a comparison was made between specimens which had been molded and those which were die cut from a flat sheet. The Dinsmore, Wright, Patrikeev Melnikov and Goodyear "tongue tear" specimens were also evaluated.

6. It has been reported[7] that a higher load for tearing is observed with increased speed. Thus a change of speed of tearing across the specimen from 300 to 1000 inches per minute is said to produce a 30% increase in load. Equipment was not available in this laboratory for measuring this speed of tearing, but using the Thwing - Albert Electro Hydraulic Tensile Tester (Fig. 1), changes in the rate of elongation were examined. Tests were performed using jaw separation speeds of 5, 20, 30 and 240 inches per minute. The latter speed represents the maximum this machine is capable of developing.

7. Two molds were made which would give rubber sheets of approximately 260 and 130 thousandths of an inch thickness. Tear specimens were die cut from these pads and from the standard tensile pads which are .080 inch thick, and a comparison of the effect of varying sample thickness was made. The number and angles of the nicks were varied on the ASTM (B) specimen. Angles of 30°, 45° and 60°, parallel and converging, were investigated.

8. The energy at failure for natural rubber, GR-S and butyl, using both ASTM (B) and Graves specimens, was calculated at various rates of elongation by measuring the area under the stress-strain curve.

9. Tear propagation by nicking a specimen 1" x 6" x .085" when held under a specified load was also investigated. The load was changed at the start of each test and the length the tear progressed was measured for this load. This procedure was continued at successively heavier loads until the specimen failed.

10. Since it appeared from information obtained in this investigation and previous work on this subject, that a definite correlation could be found between tear resistance and elongation, three tear tests and seven commercial polymers were investigated in an attempt to elucidate or define this correlation, if such could be found.

11. A compounding survey was conducted with the object of determining the effect of reinforcing filler

particle size and structure on the tear resistance. Three typical gum rubber stocks, whose formulae are furnished in Table I, were chosen for this study and consisted of natural rubber, GR-S, and butyl. Six fillers varying in particle size and structure (Table II) were incorporated into each of the base polymers. The physical properties (Table III) of tensile, elongation, modulus, Shore A hardness, Lupke resilience and compression set were determined on the resulting twenty-one compounds. A survey was made of the Graves and ASTM(B) tear tests, using ten test specimens of each of the above described compounds. After this data was analyzed, it was found desirable, for purposes of comparison, to perform the same type of survey on the standard tensile test. The same rubber stocks and number of specimens were used in this investigation and the data analyzed in the same fashion.

12. In an effort to correlate tear resistance with some fundamental property of rubber other than tensile strength, the natural rubber, GR-S, and butyl rubber compounds prepared for the compounding survey were tested, using the N.B.S. strain tester (Fig. 2) which determines the elongation produced by a given load. In connection with this same objective, various attempts were made to correlate tear resistance measurements with the radius of curvature of the test specimen.

# Results

13. Data for the specimens, which had been molded as compared with those which had been die cut from standard test pads, is presented in Table V. Tests were conducted at speeds of 5, 20, 30, and 240 inches per minute. These results indicate that there is no direct correlation between tear results determined at the various speeds nor between molded and die cut specimens.

14. The data furnished in Table VI indicates that it is not possible to achieve greater reproducibility in the tear values, using the Graves and ASTM(B) tear tests, by increasing the specimen thickness. It is also shown that there is considerable but irregular variation in the value of tear expressed in pounds per inch of thickness, depending upon the thickness of the specimen taken.

15. The "tongue" specimens gave results that were considerably lower than either ASTM (B) or Graves (Table IX). This type of specimen is more susceptible to knotty tear, and therefore gave percent average deviations greater than the ASTM (B) or the Graves specimens.

16. The angle at which the nick is initiated on the ASTM (B) specimen has little effect on the tear resistance in pounds per inch of thickness (Table VII).

As the number of nicks are increased, the tear resistance increases, indicating a more equal distribution of forces.

17. Table VIII indicates that it requires a greater load to produce failure in the GR-S than in either the butyl or Hevea stocks when the load is held constant during each test.

18. The $\frac{\text{in-lb.}}{\text{sec.}}$ of energy at failure is directly dependent upon the speed of the tester and does not seem to be related to any other physical property (Table X).

19. To study the correlation between tear resistance using the standard tear tests and elongation, tear resistance measurements were made using three standard methods on seven commercial polymers. Results (Table XI) indicate that there is some correlation between tear resistance expressed as pounds pull per inch of thickness and the percent elongation at break. The Graves test does not appear to be specific enough in values that enable adequate differentiation between various polymer stocks. Further work correlating tear and elongation might prove to be profitable.

20. The data obtained from the compounding survey previously described is presented in Tables III, XII and XIII. It will be seen that a regular increase or decrease in the value of each property measured follows the increase

in particle size of the filler, thus demonstrating the effect particle size of filler exerts on vulcanizates. Results of the data furnished in Table XII indicate that accuracy and reproducibility cannot be made a basis of choice between Graves and ASTM methods, since they both show approximately equal overall percentage average deviations. On the basis of convenience of test procedure, one would choose the Graves test method because no nick is required. The relative validity of the two methods is seen to depend to a certain extent on the type of polymer chosen for test. For example, with natural rubber, the ASTM method shows a slightly lower percentage average deviation, while with both the GR-S and butyl the reverse is true. For both types of tear tests using the various fillers in the three polymers, the overall average deviation is about 11%. Similar results for comparable studies are shown in reference 5.

21. Results of the tensile test survey (Table XIII), using the same rubber stocks as were used in the tear series above, indicate that the reproducibility of the tear tests at 11% average deviation approximates that of the tensile test at 7.5% average deviation.

22. From the data shown in Table IV, it may be seen that there is no positive correlation between tear resistance and modulus as measured by the N.B.S. strain tester.

Further efforts to correlate tear resistance with the radius of curvature in the test specimens also proved to be fruitless.

## Discussion

23. In the computations of the average deviations, the following method of rejecting doubtful measurements was utilized. Omitting the doubtful measurement, the mean of the series was computed and the average deviation of a single measurement from the mean determined. Next, the deviation of the doubtful measurement from the mean was computed. If its deviation was greater than five times the average deviation, it was rejected. This simple rule is based on the fact that granting the normal distribution law, the frequency of occurrence of an observation having a deviation from the mean greater than five times average deviation is less than one in a thousand. The percent average deviation obtained from the resulting groups of values represent pure numbers and have no relationship to the relative pound values of the tear resistance as obtained in either the ASTM(B) or Graves methods.

24. Of all the factors thus far studied in this investigation, only tensile strength bears any positive correlation with tear resistance (Table XIV). It appears also that in all tear tests thus far proposed

and described in the literature, the tear is a composite effect resulting from both a tensile and shear component of the applied stress. It would seem that the fundamental problem involved is separation of the former from the latter. The data presented herein have shown that the percent average deviations in both the tear and tensile tests are of the same order of magnitude. This demonstrates that the presently used tear tests are merely examples of a more complicated tensile test. It would seem, therefore, that there are only two courses of action which remain to be investigated. That is, one may begin with the object of improving the mechanics and reproducibility of the more basic and longer used tensile test, or one may seek some entirely new approach to a tear process which is completely divorced from the tensile, if such a test can be conceived. However, the real difficulty may be even more basic than mentioned heretofore. That is to say, one may be confronted with the enigma of attempting to obtain uniform results from a material which is in itself essentially non-homogeneous. As is well known, a laboratory technician may take a standard test pad and find that dumb-bell specimens die cut within the same 6" x 6" test pad (or even molded separately) and in the same grain direction will yield a percentage average deviation of approximately 10% when tested on the standard Scott tensile tester. Such results can be duplicated as frequently and regularly as desired, regardless of numerical value of tensile, type of filler, content of plasticizer, etc. Increasing the complexity of the dumb-bell test specimen to arrive at such specimens as the angle tear test and Crescent tear test, only serves to complicate the determination of the original tensile strength, since it has been found that a direct relationship exists between the two in each case.

25. The further investigation of tearing of rubber, it is believed, should be more valuable if the emphasis were shifted from a study of the tensile type tests and placed upon the development of a test which would more nearly reflect the condition of tearing in the majority of cases in service. As previously mentioned, this is taken to be a device which will in some manner simulate the cutting, cracking, chipping or sharp penetrations observed in failures of tires, bogie wheels, tank track blocks, etc. Of course, the same conclusions regarding non-homogeniety of the rubber will also apply in this case and one could hardly expect much greater than 10% reproducibility, but here the test would at least be more representative of conditions most frequently encountered in service.

| | |
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| Report by: | Z. T. Ossefort<br>*Z. T. Ossefort* |
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## APPENDIX I

Tear Resistance of Rubber
Project TB4-521E, Problem 1

Phase I, Basic Information for Control Purposes

A. Polymers (based on Greatest usage)

1. GR-S (Non-crystallizable)

2. GR-I (Crystallizable)

3. Natural Rubber

B. Test Specimens (Standard) and thicker

1. ASTM Specimen b

a. Un-nicked) ( cut and molded
b. Nicked )

2. Graves (Molded) and cut

C. Speed (Electro-Hydraulic Tensile Tester)

1. 5"/minute

2. 20"/ minute

3. 30"/minute

4. 240"/minute

D. Compounding Study

1. Gum Rubber Stock

2. Carbon (particle size effect)

a. Channel (HPC or finer)

b. Furnace HAF

c. Furnace SRF

d. Acetylene

e. Thermax

3. Cure

   a. For highest tear resistance

   b. For highest tensile strength

   c. Overcure

4. Softeners (Saturated Petroleum, esters and polymeric)

   a. No plasticizer

   b. Low percent plasticizer (5%)

   c. High percent plasticizer (10%)

5. Determine effect of Banbury mixing and mill rolling procedures.

E. Properties to be measured

1. Tensile strength

2. Elongation

3. Modulus

4. Durometer

5. Resilience

6. Abrasion

7. Tear resistance

   a. Initiation

   b. Propagation

F. Select one representative compound for each polymer for further tests.

Phase II, Determination of Mechanism of Tear

A. Effect of variables in test methods and conditions, using test specimens and compounds selected in Phase I.

1. Specimen size

    a. Vary thickness

    b. Vary width

2. Nicks

    a. Vary depth

    b. Vary number

    c. Vary angle

    d. Cut specimen so nick will be perdendicular to grain

    e. Cut specimen so nick will be parallel to grain

3. Determine force for initiation and propagation of tear

4. Determine energy for initiation and propagation of tear

5. Determine effect of temperature on tear resistance

6. Determine effect of very high speeds (0.5 to 1000 inches/second)

    a. Note load variations with speed

    b. Study high speed pictures of tearing

B. Effect of varying types of specimens

1. Specimens

    a. Dinsmore Specimen

        (1) Maintain thickness, speed, temperature and compounding constant

        (2) Determine force and energy for propagation of tear, both perpendicular and parallel to grain

b. Wright Specimen

(1) Same as II.B.1.a.(1)

(2) Same as II.B.1.a.(2)

c. Patrikeev & Melnikov Specimen

(1) Same as II.B.1.a.(1)

(2) Same as II.B.1.a.(2)

d. Elmendorf Method

e. Rectangular Specimen

(1) Apply a given load

(2) Nick specimen 1/8"

(3) Determine load required to cause complete failure when tear is initiated by a nick (vary applied load until complete failure occurs when nick is initiated)

(4) Photograph tear propagation with high speed camera

2. Method of Test

a. Constant rate of jaw separation

b. Constant rate of elongation

Phase III, Collation of Results and Deductions therefrom

A. Correlate tear resistance with physical properties

B. Correlate tear resistance with service tests

C. Deduce theory of mechanism of tear

D. Select best method to give desired results and reproducibility

Phase IV, Specifications

A. Determine specification limits

B. Write specification

## List of Tables and Figures

## TABLE I

## FORMULAE OF RUBBER STOCKS

| | RIA #A8 | RIA #T7 | RIA#S7F1 |
|---|---|---|---|
| Natural Rubber - Pale Crepe | 100 | - | - |
| Butyl - GRI | - | 100 | - |
| GR-S - Standard | - | - | 100 |
| Zinc Oxide | 5 | 5 | 5 |
| Stearic Acid | 1 | 3 | 1 |
| Agerite Hipar | 1 | - | - |
| Neozone D | - | - | 1 |
| Methyl Tuads | 3 | 1 | - |
| Santocure | - | - | 1 |
| Sulfur | 0.5 | 1.5 | 1.75 |
| Plastogen | 1 | - | - |
| TP 90B | - | - | 10 |
| | 111.5 | 100.5 | 129.75 |

The following six fillers were incorporated into each of the above gum stocks in the amounts shown below:

| | | | |
|---|---|---|---|
| Conductive Channel | 50 | 20 | 50 |
| Hi Sil | 54 | 22 | 54 |
| High Abrasion Furnace | 50 | 20 | 50 |
| Acetylene Black | 50 | 20 | 50 |
| Semi Reinforcing Furnace | 50 | 20 | 50 |
| Thermax | 50 | 20 | 50 |

TABLE II

PARTICLE SIZE AND DEGREE OF STRUCTURE OF FILLERS
USED IN COMPOUNDING SURVEY

| Filler | Symbol | Diam. Millimicrons | Type Agglomeration |
|---|---|---|---|
| Conductive Channel | CC | 10-20 | Normal |
| Hi Sil | -- | 25 | -- |
| High Abrasion Furnace | HAF | 36 | High |
| Acetylene Black | ACET | 43 | Very High |
| Semi-Reinforcing Furnace | SRF | 70-90 | Normal |
| Thermax | MT | 250-500 | Low |

TABLE III

PHYSICAL PROPERTIES OF RUBBER STOCKS USED IN COMPOUNDING SURVEY

50 PARTS FILLER - INCREASED PARTICLE SIZE ⟶

| | CC | HISIL | HAF | ACET | SRF | MT | GUM |
|---|---|---|---|---|---|---|---|
| **Natural Rubber A8** | | | | | | | |
| Tensile | 4060 | 3170 | 2880 | 2540 | 2300 | 2500 | 2540 |
| 300% Modulus | 1870 | 1220 | - | - | - | 850 | 125 |
| % Elongation | 500 | 600 | 300 | 350 | 340 | 460 | 650 |
| Hardness | 77 | 67 | 72 | 68 | 61 | 50 | 38 |
| Tear ASTM (B) | 960 | 440 | 530 | 285 | 300 | 120 | 110 |
| Graves | 600 | 575 | 218 | 210 | 190 | 145 | 90 |
| Lupke Rebound | 46 | 62 | 63 | 64 | 72 | 74 | 77 |
| Comp. set (B), 22 hrs. at 158°F. | 15 | 19 | 8 | 8 | 6 | 6 | 5 |
| **GF-S S7F1** | | | | | | | |
| Tensile | 2410 | 890 | 2500 | 1950 | 1770 | 640 | 160 |
| 300% Modulus | 1630 | 184 | 1500 | 1500 | 915 | 300 | 140 |
| % Elongation | 600 | 820 | 400 | 370 | 490 | 430 | 400 |
| Hardness | 66 | 54 | 58 | 64 | 53 | 47 | 40 |
| Tear ASTM (B) | 470 | 210 | 270 | 182 | 146 | 39 | 23 |
| Graves | 400 | 170 | 182 | 175 | 150 | 87 | 21 |
| Lupke Rebound | 38 | 46 | 52 | 51 | 56 | 60 | 62 |
| Comp. set (B) 22 hrs. at 158°F. | 42 | 75 | 26 | 22 | 26 | 26 | 22 |
| **Butyl I7** | | | | | | | |
| Tensile | 2620 | 2500 | 2630 | 2360 | 2300 | 2275 | 2390 |
| 300% Modulus | | | | | | | |
| % Elongation | 880 | 900 | 750 | 710 | 730 | 750 | 800 |
| Hardness | 51 | 39 | 47 | 51 | 48 | 42 | 35 |
| Tear ASTMB | 200 | 120 | 110 | 90 | 72 | 31 | 32 |
| Graves | 120 | 88 | 130 | 128 | 91 | 87 | 71 |
| Lupke Rebound | 17 | 18 | 17 | 17 | 17 | 20 | 19 |
| Comp. set (B) 22 hrs. at 158°F. | 27 | 17 | 19 | 19 | 24 | 35 | 18 |

Stress-strain data in this table were obtained using the Scott Tensile Tester and standard procedure.

TABLE IV
COMPARISON OF TEAR RESISTANCE WITH STRAIN TESTS

| Polymer | Tear | | N.B.S. Strain | | |
|---|---|---|---|---|---|
| | ASTM (B) | Graves | 100 psi. | 200 psi. | 400 psi. |
| Hevea - CC | 904 | 486 | 11 | 48 | 122 |
| Hevea - Hi Sil | 506 | 232 | 9 | 68 | 179 |
| Hevea - HAF | 583 | 161 | 16 | 44 | 92 |
| Hevea - Acet. | 418 | 170 | 19 | 54 | 104 |
| Hevea - SRF | 397 | 147 | 27 | 67 | 137 |
| Hevea - MT | 196 | 133 | 50 | 137 | 233 |
| Hevea - Gum | 218 | 81 | 97 | 258 | 432 |
| GR-S - CC | 358 | 170 | 40 | 144 | 280 |
| GR-S - Hi Sil | 262 | 134 | 147 | 298 | 528 |
| GR-S - HAF | 283 | 161 | 46 | 117 | 185 |
| GR-S - Acet. | 219 | 162 | 34 | 88 | 150 |
| GR-S - SRF | 182 | 152 | 61 | 142 | 242 |
| GR-S - MT | 84 | 70 | 93 | 213 | 364 |
| GR-S - Gum | 43 | 11 | 115 | - | - |
| Butyl - CC | 265 | 102 | 155 | 346 | 527 |
| Butyl - Hi Sil | 190 | 76 | 235 | 452 | 623 |
| Butyl - HAF | 150 | 108 | 78 | 191 | 350 |
| Butyl - Acet. | 148 | 93 | 84 | 205 | 371 |
| Butyl - SRF | 104 | 83 | 97 | 240 | 369 |
| Butyl - MT | 55 | 56 | 134 | 317 | 506 |
| Butyl - Gum | 48 | 60 | 186 | 375 | - |

TABLE V

TEAR RESISTANCE MEASUREMENTS OF GRAVES AND ASTM (B) MOLDED SPECIMENS VERSUS DIE CUT SPECIMENS

| Speed | RIA Compound | Graves Die Cut Av. Tear | Ave. Dev. | % Ave. Dev. | % Elong. | Graves Molded Ave. Tear | Ave. Dev. | % Ave. Dev. | % Elong. |
|---|---|---|---|---|---|---|---|---|---|
| 5"/min. | S7 | 170 | 7 | 4 | 100 | 166 | 17 | 10 | 106 |
| 20"/min. | S7 | 176 | 17 | 10 | 114 | 163 | 24 | 15 | 114 |
| 30"/min. | S7 | 195 | 15 | 8 | 105 | 180 | 22 | 12 | 100 |
| 5"/min. | I7 | 110 | 4 | 4 | 400 | 106 | 11 | 10 | 190 |
| 20"/min. | I7 | 115 | 2.4 | 2 | 420 | 120 | 9 | 8 | 187 |
| 30"/min. | I7 | 118 | 4.4 | 4 | 375 | 135 | 11 | 8 | 205 |
| | | ASTM(B) Die Cut Ave. Tear | | | | ASTM(B) Molded Ave. Tear | | | |
| 5"/min. | S7 | 203 | 17 | 8 | 158 | 184 | 33 | 18 | 173 |
| 20"/min. | S7 | 187 | 20 | 11 | 150 | 181 | 15 | 8 | 139 |
| 30"/min. | S7 | 163 | 16 | 10 | 115 | 220 | 21 | 10 | 153 |
| 5"/min. | I7 | 221 | 47 | 21 | 550 | 147 | 25 | 17 | 335 |
| 20"/min. | I7 | 180 | 65 | 36 | 500 | 141 | 6 | 4 | 335 |
| 30"/min. | I7 | 170 | 45 | 26 | 445 | 185 | 31 | 17 | 360 |
| | | Graves Die Cut | | | | ASTM Die Cut | | | |
| 240"/min. | A8EPC | 230 | 38 | 17 | - | | | | |
| 240"/min. | A8EPC | | | | | 495 | 54 | 10 | |
| | | | | | | Un-nicked | | | |
| 240"/min | A8EPC | | | | | 649 | 88 | 14 | |

All values shown represent averages of ten tear specimens.

TABLE VI

EFFECT OF VARIATION OF SAMPLE THICKNESS ON THE REPRODUCIBILITY OF TEAR RESULTS USING THE GRAVES AND ASTM (B) METHODS

| RIA # - Polymer | Thickness | Speed | Tear | Ave.Dev. | % Ave.Dev. | % Elong. at Break |
|---|---|---|---|---|---|---|
| | | | GRAVES - DIE CUT | | | |
| A8 - Hevea | .267 | 5"/min. | 397 | - | - | - |
| A8 - Hevea | .267 | 30"/min. | 360 | 42 | 12 | - |
| A8 - Hevea | .129 | 5"/min. | 350 | 42 | 12 | 94 |
| A8 - Hevea | .130 | 30"/min. | 335 | 31 | 9 | 100 |
| A8 - Hevea | .090 | 20"/min. | 265 | Scott tensile tester, using standard procedure. | | |
| A8 - Hevea | .093 | 20"/min. | 290 | 30 | 10 | 190 |
| S7F1-GR-S | .244 | 30"/min. | 234 | - | - | - |
| S7F1-GR-S | .129 | 5"/min. | 163 | 14 | 9 | 113 |
| S7F1-GR-S | .129 | 30"/min. | 163 | 11 | 7 | 94 |
| S7F1-GR-S | .092 | 20"/min. | 180 | Scott tensile tester, using standard procedure. | | |
| S7F1-GR-S | .093 | 20"/min. | 186 | | | 230 |
| | | | ASTM (B) - DIE CUT | | | |
| A8-Hevea | .269 | 20"/min. | 405 | 81 | 20 | 150 |
| A8-Hevea | .127 | 20"/min. | 400 | 164 | 40 | 152 |
| A8-Hevea | .093 | 20"/min. | 600 | Scott Tester | | |
| S7F1-GR-S | .245 | 20"/min. | 315 | 17 | 6 | 245 |
| S7F1-GR-S | .127 | 20"/min. | 315 | 26 | 12 | 189 |
| S7F1-GR-S | .093 | 20"/min. | 291 | Scott Tester | | |

## TABLE VII

### EFFECT OF ANGLE AND NUMBER OF NICKS IN THE ASTM (B) SPECIMEN

| Com-Pound | No. Nicks | Angle of Nicks | Tear Resistance Ave. lb./in. | Ave. Dev. Lbs. | % Ave. Dev. |
|---|---|---|---|---|---|
| A8 | 1 | 30° | 479 | 31 | 6.5 |
| A8 | 1 | 45° | 465 | 22 | 4.8 |
| A8 | 1 | 60° | 508 | 20 | 4.0 |
| S7F1 | 1 | 30° | 207 | 11 | 5.4 |
| S7F1 | 1 | 45° | 199 | 10 | 5.0 |
| S7F1 | 1 | 60° | 209 | 10 | 4.8 |
| I7 | 1 | 30° | 90 | 2 | 2.2 |
| I7 | 1 | 45° | 108 | 5 | 4.6 |
| I7 | 1 | 60° | 114 | 11 | 9.7 |
| A8* | 2 | 30° | 459 | 25 | 5.5 |
| A8* | 2 | 45° | 472 | 25 | 5.3 |
| A8* | 2 | 60° | 473 | 78 | 16.5 |
| S7F1* | 2 | 30° | 237 | - | - |
| S7F1* | 2 | 45° | 225 | 27 | 12 |
| S7F1* | 2 | 60° | 254 | 30 | 11.8 |
| I7* | 2 | 30° | 98 | 7 | 7.2 |
| I7* | 2 | 45° | 84 | 3 | 3.6 |
| I7* | 2 | 60° | 118 | 7 | 5.9 |
| A8** | 2 | 30° | 431 | 55 | 12.8 |
| A8** | 2 | 45° | 455 | 55 | 12.1 |
| A8** | 2 | 60° | 462 | 60 | 13.0 |
| S7F1** | 2 | 30° | 209 | 20 | 9.6 |
| S7F1** | 2 | 45° | 209 | 3 | 1.5 |
| S7F1** | 2 | 60° | 189 | - | - |
| I7** | 2 | 30° | 85 | 12 | 14.2 |
| I7** | 2 | 45° | 93 | 5 | 5.4 |
| I7** | 2 | 60° | 84 | 5 | 6.0 |

* Angles measured from opposite sides of the perpendicular.

** Angles parallel. All nicks 0.02" deep, speed 20"/min.

NOTE: All compounds shown were mixed using HAF carbon black.

TABLE VIII

TEAR PROPAGATION

| Compound | Thick ness | Load | Lb./in. | Length of Tear |
|---|---|---|---|---|
| A8-HAF | .090 | 20 | 222 | .156 |
| A8-HAF | .093 | 30 | 323 | .156 |
| A8-HAF | .089 | 32.5 | 366 | Failure |
| S7F1-HAF | .088 | 30 | 341 | .187 |
| S7F1-HAF | .090 | 40 | 445 | .187 |
| S7F1-HAF | .090 | 45 | 500 | .282 |
| S7F1-HAF | .087 | 47.5 | 546 | Failure |
| I7-HAF | .086 | 10 | 116 | .187 |
| I7-HAF | .089 | 11 | 124 | .250 |
| I7-HAF | .089 | 12.5 | 141 | Failure |

TABLE IX

TEAR RESISTANCE MEASUREMENTS OF TONGUE TEAR SPECIMENS

| | Compound | | |
|---|---|---|---|
| | A8-HAF | S7F1-HAF | I7-HAF |
| DINSMORE | | | |
| Ave. Lb./in. | 96 | 85 | 12 |
| Ave. Dev. lb./in. | 10 | 24 | 2 |
| % Ave. Deviation | 10 | 28 | 18 |
| WRIGHT | | | |
| Ave. lb./in. | 455 | 321 | 130 |
| Ave. Dev. lb./in. | 62 | 13 | 11 |
| % Ave. Deviation | 14 | 4 | 9 |
| PATRIKEEV & MELNIKOV $A = 60^{\circ}$ | | | |
| Ave. lb./in. | 117 | 108 | 55 |
| Ave. Dev. lb./in. | 29 | 16 | 21 |
| % Ave. Deviation | 25 | 14 | 38 |
| GOODYEAR | | | |
| Ave. Lb./in. | 15 | 26 | - |
| Ave. Dev. lb./in. | 5 | 2 | - |
| % Ave. Deviation | 33 | 9 | - |

TABLE X

ENERGY AT BREAK OF ASTM (B) AND GRAVES SPECIMENS

| | 0.6" min. | | | 1.5"/min. | | | 3.0"/min. | | | 8.0"/min. | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | % Elong. | Lb./in. | in-lb./Sec. | % Elong. | Lb./in. | in-lb./Sec. | % Elong. | Lb./in. | in-lb./Sec. | % Elong. | Lb./in. | in-lb./Sec. |
| **ASTM (B)** | | | | | | | | | | | | |
| A8-HAF | 730 | 715 | .319 | 647 | 617 | .791 | 718 | 759 | 1.25 | 668 | 632 | 2.95 |
| S7F1-HAF | 538 | 245 | .090 | 533 | 255 | .258 | 592 | 299 | .535 | 545 | 317 | 1.37 |
| I7-HAF | 715 | 118 | .049 | 973 | 176 | .348 | 853 | 140 | .278 | 725 | 122 | .607 |
| **GRAVES** | | | | | | | | | | | | |
| A8-HAF | 415 | 279 | .091 | 502 | 361 | .367 | 385 | 314 | .608 | 413 | 342 | 2.33 |
| S7F1-HAF | 502 | 176 | .071 | 505 | 195 | .174 | 288 | 189 | .353 | 312 | 212 | .92 |
| I7-HAF | 783 | 116 | .043 | 903 | 130 | .106 | 763 | 121 | .181 | 833 | 138 | .558 |

| | 20"/min. | | | 30"/min. | | | 40"/min. | | |
|---|---|---|---|---|---|---|---|---|---|
| | % Elong. | Lb./in. | in-lb./Sec. | % Elong. | Lb./in. | in-lb./Sec. | % Elong. | Lb./in. | in-lb./Sec. |
| **ASTM (B)** | | | | | | | | | |
| A8-HAF | 660 | 605 | 7.24 | 650 | 649 | 11.0 | 612 | 589 | 13.6 |
| S7FI-HAF | 513 | 266 | 3.4 | 542 | 250 | 5.31 | 653 | 364 | 7.51 |
| I7-HAF | 855 | 159 | 1.78 | 1190 | 228 | 3.59 | 900 | 163 | 2.93 |
| A8-HAF | 402 | 280 | 3.41 | 335 | 247 | 3.39 | 323 | 261 | 5.62 |
| S7F1-HAF | 520 | 227 | 2.35 | 582 | 244 | 4.67 | 582 | 245 | 5.29 |
| I7-HAF | 1005 | 162 | 1.93 | 780 | 139 | 2.58 | 777 | 106 | 3.37 |

TABLE XI
INVESTIGATION OF RELATIONSHIP BETWEEN TEAR
RESISTANCE AND ELONGATION AT BREAK

| Width | psi. | A1 Natural Rubber | S1-GR-S | N-3 Paracril 18 | GN M-2 Neoprene | OR-15 H-5 Hycar |
|---|---|---|---|---|---|---|
| .250 | Tensile - % Elong. | 2675-650 | 1650-690 | 850-1120 | 1695-700 | 1350-980 |
| .400 | Unnicked Crescent % Elong. | 710-500 | 550-500 | 310-800 | 640-550 | 425-760 |
| .380 | Nicked Crescent % Elong. | 625-300 | 300-250 | 275-430 | 230-275 | 255-500 |
| .500 | Graves - % Elong. | 370-135 | 360-150 | 240-300 | 180-140 | 168-425 |
| Based on Equivalent Thickness and Width | | | | | | |
| .500 | Tensile - % Elong. | 1475-575 | 1060-630 | 425-1120 | 850-700 | 675-980 |
| .500 | Unnicked Crescent % Elong. | 890-500 | 685-500 | 388-800 | 800-550 | 532-760 |
| .500 | Nicked Crescent % Elong. | 822-300 | 657-250 | 362-430 | 320-275 | 335-500 |
| .500 | Graves - % Elong. | 370-135 | 360-150 | 240-300 | 180-140 | 168-425 |

| Width | psi | I2 Butyl | P1 Thiokol |
|---|---|---|---|
| .250 | Tensile - % Elongation | 835-510 | 920-400 |
| .400 | Unnicked Crescent - % Elong. | 465-310 | 380-300 |
| .380 | Nicked Crescent - % Elong. | 200-175 | 189-140 |
| .500 | Graves - % Elongation | 134-100 | 133-50 |
| Based on Equivalent Thickness and Width | | | |
| .500 | Tensile - % Elongation | 665-350 | 535-365 |
| .500 | Unnicked Crescent - % Elong. | 595-310 | 475-300 |
| .500 | Nicked Crescent - % Elong. | 263-175 | 248-140 |
| .500 | Graves - % Elongation | 134-100 | 133-50 |

TABLE XII

PERCENTAGE AVERAGE DEVIATIONS IN TEAR RESULTS
OF HEVEA, GR-S, AND BUTYL FILLED WITH VARIOUS PARTICLE SIZED FILLERS

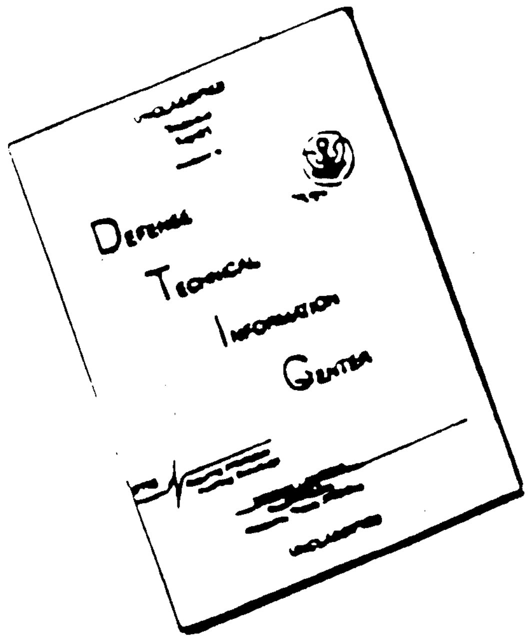
| | | NATURAL RUBBER-A8 | | | GR-S - S7F1 | | | BUTYL I7 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| Filler | Method | Tear lb/in. | Ave. Dev. Lbs. | % Ave. Dev. | Tear Lb/in. | Ave. Dev. Lbs. | % Ave. Dev. | Tear lb/in. | Ave. Dev. Lbs. | % Ave. Dev. |
| CC | ASTM | 904 | 54 | 6.0 | 358 | 72 | 20 | 265 | 15 | 5.7 |
| CC | Graves | 486 | 97 | 20.2 | 170 | 16 | 9.3 | 102 | 5 | 5.0 |
| HiSil | ASTM | 506 | 79 | 15.6 | 262 | 14 | 5.4 | 190 | 18 | 9.5 |
| HiSil | Graves | 232 | 72 | 31.0 | 134 | 15 | 11.0 | 76 | 4 | 5.5 |
| HAF | ASTM | 583 | 48 | 8.2 | 283 | 37 | 13.1 | 150 | 14 | 9.5 |
| HAF | Graves | 161 | 21 | 13.0 | 161 | 9.6 | 6.0 | 108 | 8 | 7.7 |
| Acet. | ASTM | 418 | 27 | 6.4 | 219 | 23 | 10.1 | 148 | 50 | 20.2 |
| Acet. | Graves | 170 | 30 | 17.7 | 162 | 5.3 | 3.3 | 93 | 5 | 5.5 |
| SRF | ASTM | 397 | 51 | 12.8 | 182 | 18 | 9.7 | 104 | 15.4 | 15.0 |
| SRF | Graves | 147 | 16 | 11.1 | 152 | 5.6 | 3.7 | 83 | 5.9 | 7.1 |
| MT | ASTM | 196 | 55 | 28.0 | 84 | 13.7 | 16.3 | 55 | 7.1 | 13.0 |
| MT | Graves | 133 | 11 | 8.3 | 70 | 5.2 | 7.5 | 56 | 11.3 | 20.2 |
| Gum | ASTM | 218 | 18 | 8.3 | 43 | 2.6 | 6.0 | 48 | 4.3 | 9.0 |
| Gum | Graves | 81 | 7.6 | 9.4 | 11 | 1.3 | 11.8 | 60 | 7.4 | 12.3 |
| TOTALS | ASTM | | | 12.2 | | | 11.5 | | | 11.7 |
| | Graves | | | 15.8 | | | 7.5 | | | 9.0 |

TABLE XIII
PERCENTAGE AVERAGE DEVIATIONS IN TENSILE RESULTS

| | NATURAL RUBBER-A8 | | | GRS-S7F1 | | | BUTYL I7 | | |
|---|---|---|---|---|---|---|---|---|---|
| Filler | Tensile psi | Ave. Dev. | % Ave. Dev. | Tensile psi | Ave. Dev. | % Ave. Dev. | Tensile psi | Ave. Dev. | % Ave. Dev. |
| CC | 4070 | 215 | 5.3 | 2600 | 115 | 4.7 | 2370 | 86 | 3.6 |
| HiSil | 2835 | 65 | 2.3 | 1000 | 67 | 6.7 | 2140 | 109 | 5.1 |
| HAF | 2920 | 170 | 5.8 | 2175 | 240 | 11.0 | 2100 | 168 | 8.0 |
| ACET. | 2200 | 164 | 7.4 | 1890 | 103 | 5.4 | 1760 | 259 | 14.7 |
| SRF | 1840 | 140 | 7.6 | 1710 | 66 | 3.9 | 1840 | 123 | 6.7 |
| MT | 1980 | 162 | 8.2 | 570 | 77 | 13.6 | 1560 | 240 | 15.5 |
| GUM | 1850 | 84 | 4.5 | - | - | - | 2220 | 215 | 9.7 |
| TOTALS | | | 5.9 | | | 7.5 | | | 9.0 |

Ten specimens were used in each case and the data analyzed as described in report.

# DISCLAIMER NOTICE



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